22.211 Homework 4

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Overview

All code used in this problem set is available on github at: https://github.com/icmeyer/22.211.git This homework can be found in the folder "pset4".

In the following problems OpenMC was run with the specifications in Table 1. Standard deviations on values as reported by OpenMC are included in all plots, but in most cases are too small to be visible.

Table 1: OpenMC Settings

Fuel Pin Diameter	1.0 cm
Fuel Temperature	900 K
Moderator Temperature	600 K
Energy cutoff	1e-8 eV
Batches (Inactive)	100 (10)
Particles	1000

In many of the problems, the four individual factors of the four factor formula are plotted. The four factor formula is defined as:

$$k_{inf} = \eta f p \epsilon$$

Where the factors have the definitions outlined in Table 2.

Table 2: Four Factor Formula

Factor	Name	Meaning	OpenMC Calculation
η	Reproduction	$\frac{\text{neutrons from fission}}{\text{absorption in fuel}}$	$\frac{\text{Thermal Fission}}{\text{Fuel Thermal Absorption}}$
f	Thermal Utilization	$\frac{\text{absorption in fuel}}{\text{all absorption}}$	$\frac{\text{Fuel Thermal Absorption}}{\text{Thermal Absorption}}$
p	Resonance Escape Probability	$\frac{\text{neutrons slowed to thermal energy}}{\text{neutrons from fission}}$	$\frac{\text{Thermal Absorption}}{\text{All Absorption}}$
ϵ	Fast Fission	$\frac{\text{neutrons from fission}}{\text{neutrons from thermal fission}}$	$\frac{\text{Fission}}{\text{Thermal Fission}}$

We can prove that these factors make up k_{inf} by "unit" analysis:

$$k_{inf} = \frac{\text{Thermal Fission}}{\text{Fuel Thermal Absorption}} \frac{\text{Fuel Thermal Absorption}}{\text{Thermal Absorption}} \frac{\text{Thermal Absorption}}{\text{All Absorption}} \frac{\text{Fission}}{\text{Thermal Fission}} = \frac{\text{Fission}}{\text{All Absorption}}$$

Problem 1

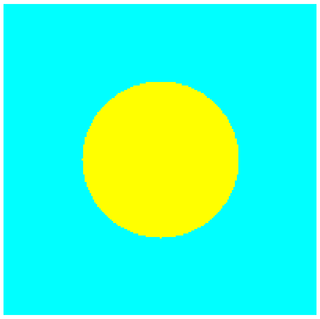


Figure 1: Heavy Water Geometry

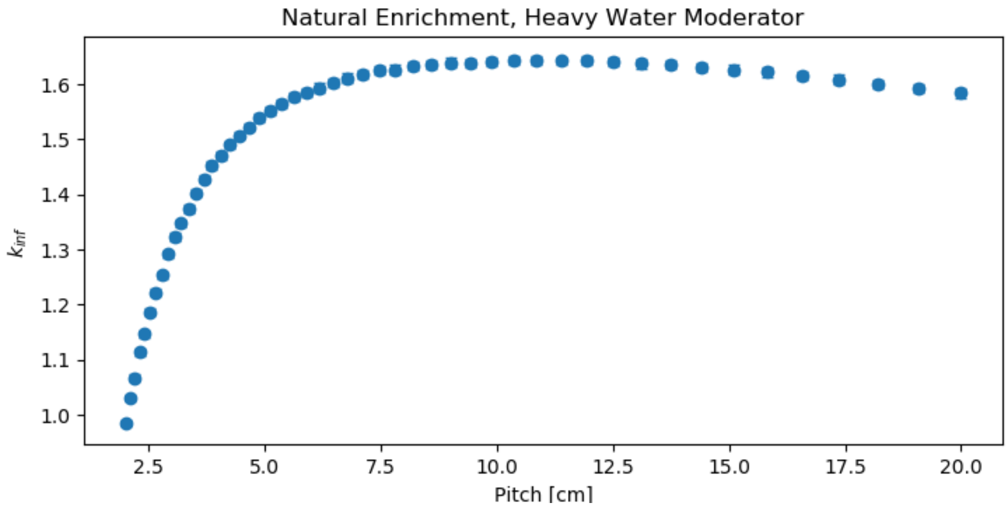


Figure 2: k_{inf} as a function of rod pitch

A) The optimal design is the point at which k_{inf} is the highest. In this case that occurs at a pitch of 10.86 cm which yields a k_{inf} of 1.6443 ± 0.0074.

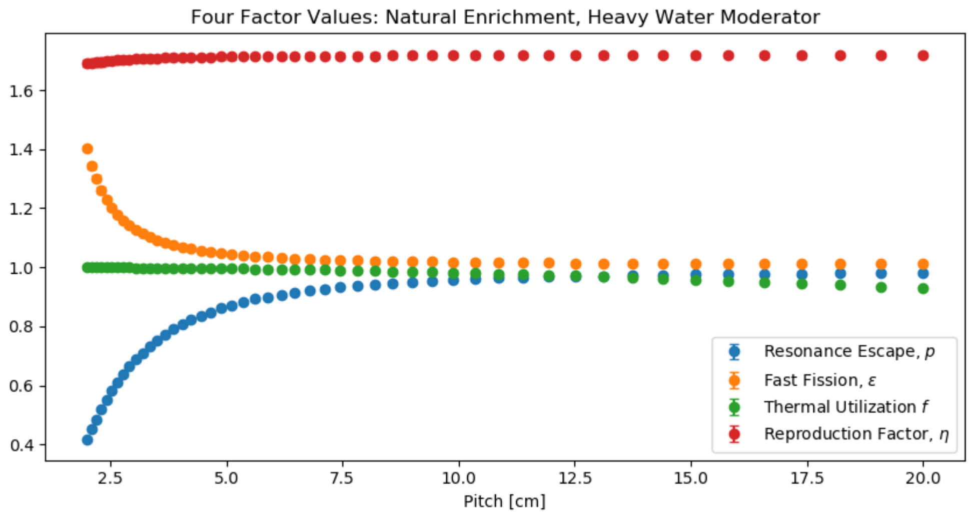


Figure 3: Four Factor Values

B) Figure 3 shows the behavior we would expect in a heavy water reactor. At a low pitch, the fast fission factor diverges because the flux is less moderated. Another effect of low moderation is high resonance escape probability, as neutrons re-enter the fuel before being fully moderated. Even though heavy water has a lower absorption cross section than light water, an increase in pitch will still decrease the thermal utilization as more neutrons are absorbed in the moderator.

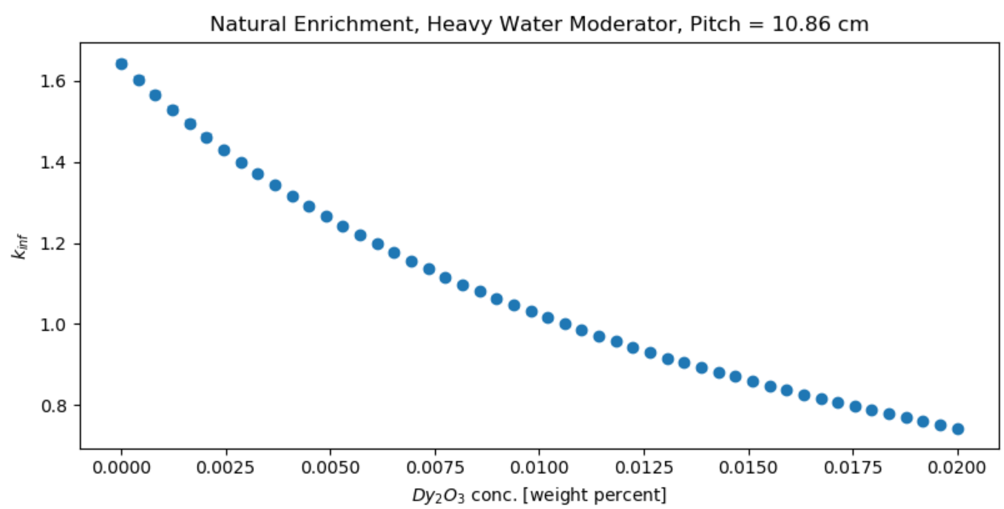


Figure 4: k_{inf} as a function of dysprosium oxide concentration with a fixed pitch

C) From 4, we can see the concentration needed is 0.0106 weight percent Dy_3O_2 for a k_{inf} of 0.9996 ± 0.0050.

Problem 2

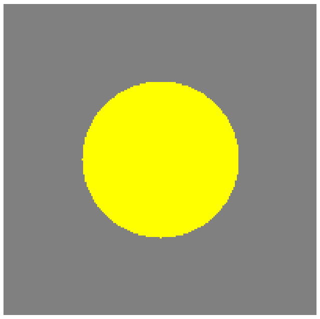


Figure 5: Graphite Geometry

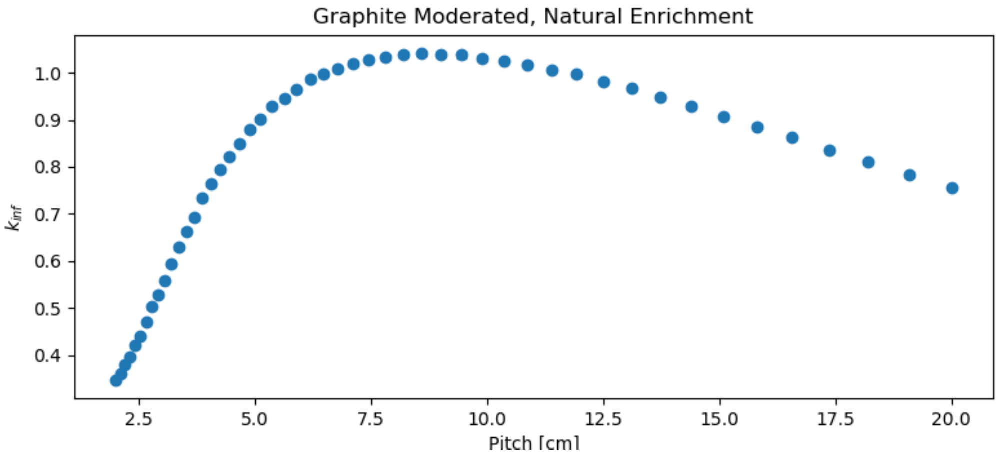


Figure 6: k_{inf} as a function of rod pitch

A) The optimal design is the point at which k_{inf} is the highest. In this case that occurs at a pitch of 8.58 cm which yields a k_{inf} of 1.0406 ± 0.0050.

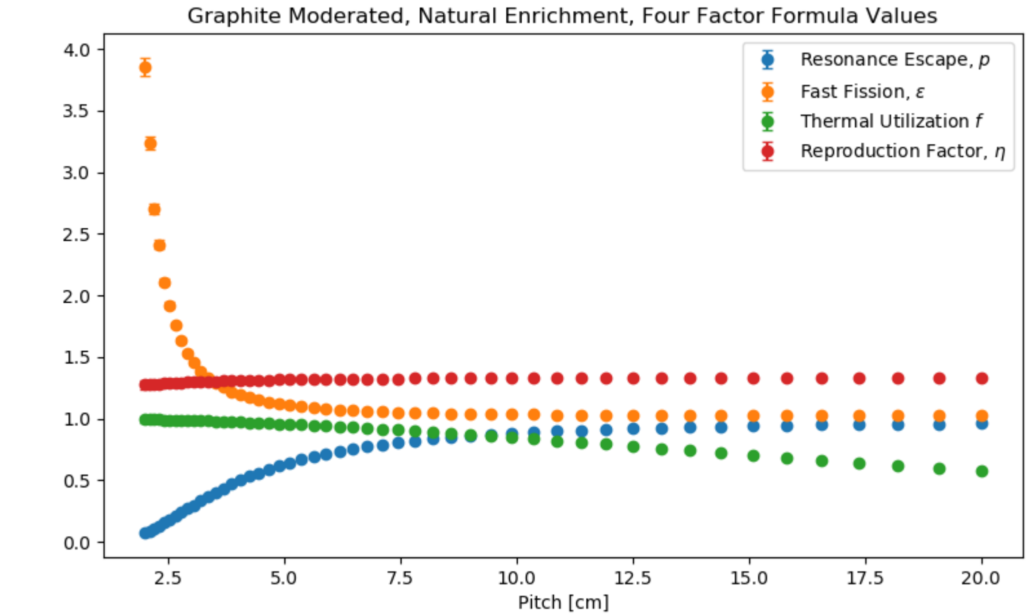


Figure 7: Four Factor Values

B) In Figure 7 we can notice some differences in the behavior of the four factors in the graphite moderated problem compared to the heavy water one. Namely, the thermal utilization drops faster as a function of pitch and the fast fission factor diverges more rapidly as pitch is decreased.

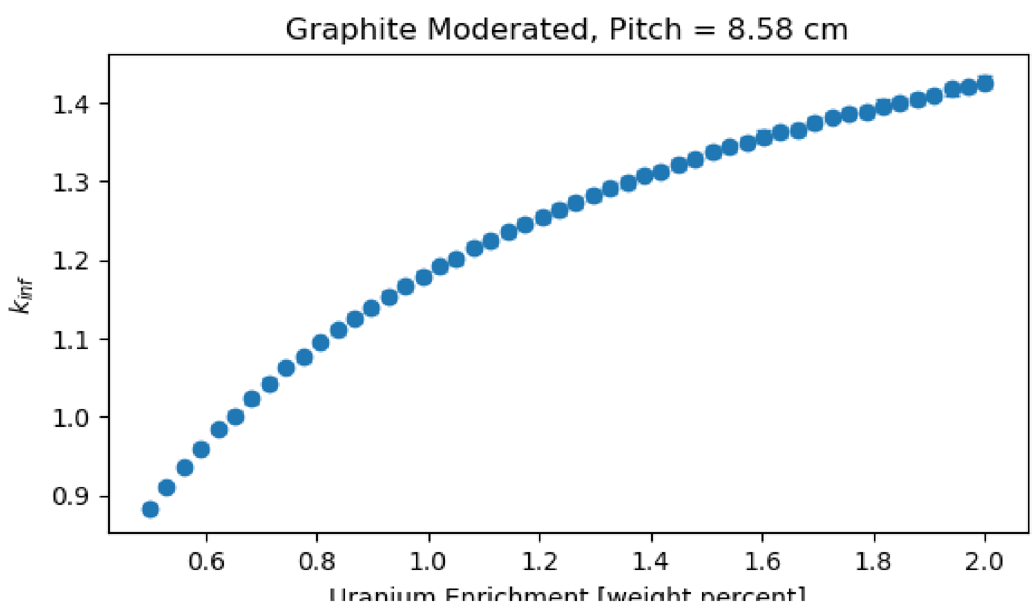
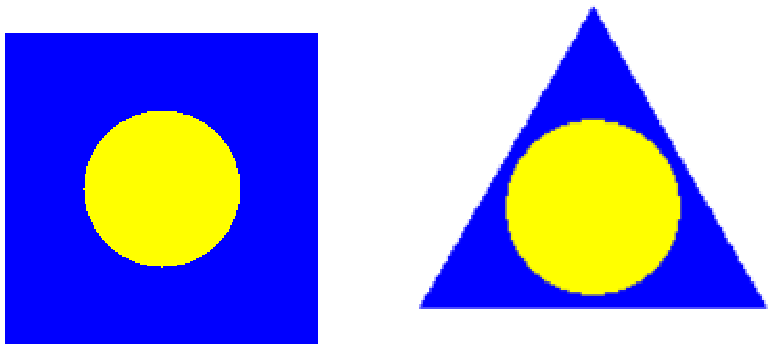


Figure 8: k_{inf} as a function of enrichment with a fixed pitch

C) From Figure 8, we can see the enrichment needed is 0.653 weight percent U_{235} for a k_{inf} of 1.0017 ± 0.0050. This is lower than the natural enrichment of uranium. At first this may seem odd, but if a super critical infinite geometry can be achieved with natural enrichment, then it follows that a barely critical configuration would require lower than natural enrichment. Also, CP-1 was a graphite moderated reactor that ran on natural uranium!

Problem 3



(a) square (b) triangle

Figure 9: Light Water Geometries

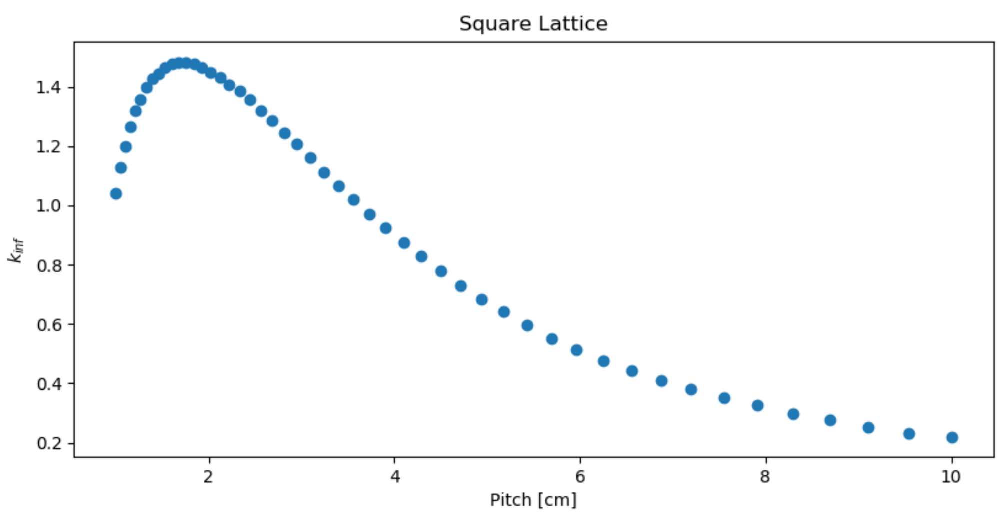


Figure 10: k_{inf} as a function of pitch with 4% enrichment

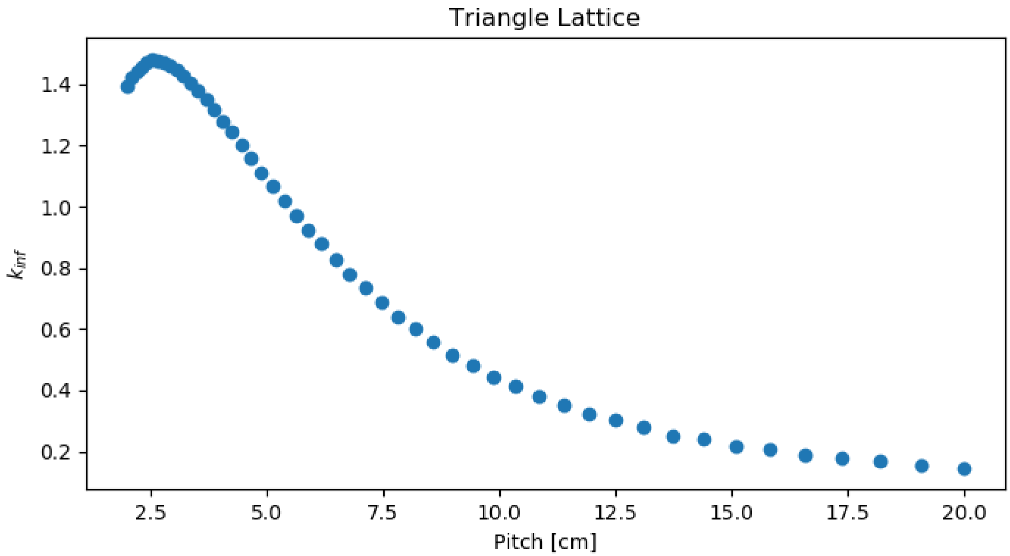


Figure 11: k_{inf} as a function of pitch with 4% enrichment

A) The optimal square pitch is 1.76 cm for a k_{inf} of 1.4830 ± 0.0072.
The optimal triangular pitch is 2.53 cm for a k_{inf} of 1.4780 ± 0.0072.

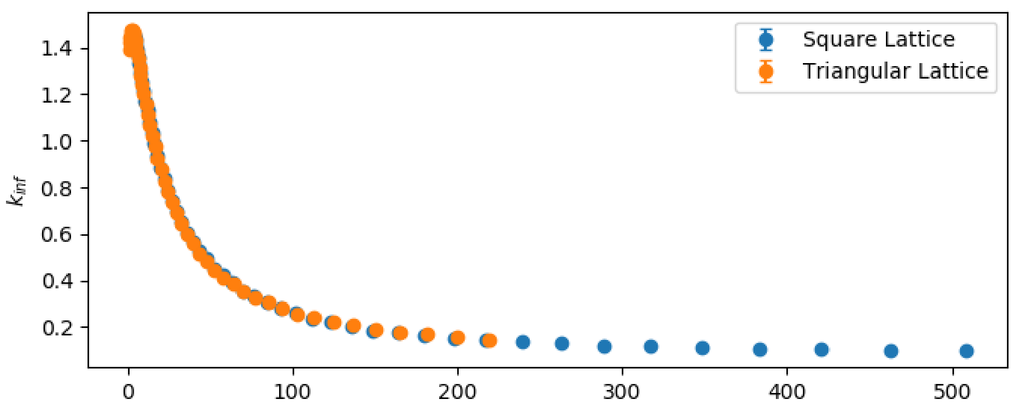


Figure 12: k_{inf} as a function of moderator to fuel ratio

B) In 12 we can see that square and triangular lattices are equivalent when compared by fuel to moderator ratio. For k_{inf} this makes sense because the shape of the lattice we choose is arbitrary when looking at an array of infinite pins.